CINCINNATI ARCH PROVINCE (066)

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With a section on the Devonian Black Shale Gas Play (6604)
by R.T. Ryder and J.R. Hatch

INTRODUCTION

The Cincinnati Arch Province (066) consists of broad, basement-involved arches, domes, and intervening sags and saddles that separate the Appalachian and Illinois Basins. A veneer of Paleozoic sedimentary rocks, as much as 5,000 ft thick, covers the basement rocks. From north to south, the Cincinnati Arch Province includes western Ohio, north-central Indiana, central Kentucky, central Tennessee, and northernmost Alabama.

In a clockwise direction, starting in northernmost Ohio and adjoining Indiana, the Cincinnati Arch is bounded by the following provinces: Michigan Basin (063), Appalachian Basin (067), Black Warrior Basin (065), and Illinois Basin (064). The southern and central parts of the Cincinnati Arch are subdivided into the Nashville Dome of central Tennessee, the Jessamine (Lexington) Dome of central Kentucky, and the intervening Cumberland Saddle. North of the Cincinnati Arch proper, which is centered near Cincinnati, Ohio, the arch bifurcates into an eastern positive element, the Findlay Arch, and a western positive element, the Kankakee Arch. The Findlay Arch plunges northeastward into the Chatham Sag in Ontario, Canada, and reappears farther north as the Algonquin Arch.

The Cincinnati Arch Province (066) covers an area of about 65,000 sq mi. The province is 500 mi long from north to south and between 100 and 250 mi wide from west to east.

The first commercial oil production in the Cincinnati Arch Province (066) was established in 1829 in the Cumberland Saddle. This oil was produced from the Upper Ordovician Sunnybrook limestone in the Great American well in Cumberland County, Kentucky. The depth to the reservoir was about 171 ft. In 1866, oil was discovered in the Tennessee part of the Cumberland Saddle at the Eagle Creek field, Overton County, Tennessee. Two zones in the Sunnybrook limestone, at depths of about 700 and 900 ft, produced the oil.

The giant Lima-Indiana oil and gas field was discovered at a depth of about 1,100 ft on the Findlay Arch in 1884. An extensively dolomitized upper part of the Middle Ordovician Trenton Limestone constitutes the prolific reservoir. The discovery well drilled near Findlay, Ohio produced only gas, but by 1886 many of the wells in Ohio also produced oil. The field was extended to the Kankakee Arch of Indiana with the discovery of gas in 1885 and oil in 1889. Careless production techniques essentially squandered the approximately 1.0 TCFG in the gas cap by 1891 in Ohio and by the early 1900's in Indiana. Subsequent oil production reached its peak in 1897 and 1906 in Ohio and Indiana, respectively. By 1910, about 85 percent of the recoverable 500 MMBO in the field had been produced. Approximately 100,000 wells have been drilled in the Lima-Indiana field.

In 1909, the first commercial oil from Cambrian and Lower Ordovician dolomite (Knox Dolomite) was discovered on the Cincinnati Arch. This oil was found on the Findlay Arch in a deeper pool of the Tiffin field (Seneca Co., Ohio) at a depth of about 2,200 ft. Additional oil in the Knox Dolomite part of the field was discovered in 1938. This small field produced about 55,000 barrels of oil through 1958.

The first commercial oil production from the Knox Group in the Cumberland Saddle probably was discovered in 1915 in the Beech Bottom field (Clinton Co., Ky.). Several Knox oil fields (Gradyville East and Pickett Chapel Exie South), ranging in size from 1 to 1.5 MMBO, were discovered in the Kentucky part of the Cumberland Saddle in the 1960's and 1970's. Bioclastic limestone reservoirs in the Middle and Upper Ordovician Lexington Limestone (Granville zone and Sunnybrook limestone of drillers) also produce oil in the Cumberland Saddle. Commonly, fields have commingled production from Granville, Sunnybrook, and Knox reservoirs. The Ordovician limestone fields are similar in size to the Knox dolomite fields.

The largest oil and gas fields in the Cumberland Saddle were discovered between 1918 and 1929 in vuggy dolomite and local sandstone of Late Silurian and Middle Devonian age, commonly known as the "Corniferous" pay. Drilling depths to the reservoirs are less than 1,000 ft. The four largest "Corniferous" fields are in Kentucky. In order of increasing size, these fields are Logsdon Valley, discovery date 1931, ultimate recovery 2 MMBO; Le Grands, discovery date 1929, ultimate recovery 4 MMBO; Bowling Green, discovery date 1918, ultimate recovery 2 MMBO; and Greensburg, discovery date 1959, ultimate recovery 22 MMBO. Several of these oil fields have large gas caps, of which Campbellsville and Hiseville Center fields are the largest. These gas fields may have each produced as much as 25 BCFG.

Modest quantities of oil and gas are produced from vuggy, bioclastic, cherty limestone reservoirs of Early Mississippian age in the Cumberland Saddle. The reservoirs are commonly referred to as reefs or bioherms. In the early 1900's, the first Lower Mississippian oil fields of importance were discovered in Wayne County, Kentucky. They produced oil and associated gas from the Beaver "sand," the lower of three reservoir zones in cherty limestone of the Fort Payne Formation. Another group of Lower Mississippian fields were discovered in Metcalfe County, Kentucky, in the late 1950's and early 1960's. These fields produced from middle and upper reservoir zones in the Lower Mississippian Fort Payne Formation. Each of the largest five fields in the Fort Payne reefs are about 1–2 MMBO in size.

Recent oil and gas exploration in the Cincinnati Arch Province has been most active in the Cumberland Saddle. The main exploration targets are vuggy dolomite in the Cambrian and Lower Ordovician Knox Group and fractured limestone reservoirs in the Middle Ordovician High Bridge and Stones River Groups. Several high-yield wells, initially producing 130–400 barrels of oil per hour in fractured limestone reservoirs of the High Bridge Group, were drilled in the early 1990's in Clinton County, Kentucky.

The Cincinnati Arch has produced an estimated 580 MMBO and 1.2 TCFG through 1993. The following conventional plays are recognized in the Cincinnati arch province: Cambrian and Lower Ordovician Carbonate Play (6601), Middle and Upper Ordovician Carbonate Play (6602), Silurian and Devonian carbonate play (6603), and Mississippian Carbonate Play (6605). One unconventional continuous-type play is also recognized, the Devonian Black Shale Gas Play (6604).

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CONVENTIONAL PLAYS

6601. CAMBRIAN AND LOWER ORDOVICIAN CARBONATE PLAY

The Cambrian and Lower Ordovician Carbonate Play is defined by oil and associated gas trapped in vuggy platform dolomite of Cambrian and Early Ordovician age by truncation traps beneath the widespread Knox unconformity and by small anticlines controlled by basement fault blocks. Stratigraphically, the play involves the Upper Cambrian Copper Ridge Dolomite of the Knox Group, Lower Ordovician Mascot Dolomite of the Knox Group, and Upper Cambrian and Lower Ordovician Knox Dolomite. The play is confirmed and extends across the entire Cincinnati Arch Province. The dolomite reservoirs in the play are classified as conventional.

Reservoirs: Primary reservoirs in the play are vuggy dolomite formed by karst processes. Commonly, these reservoirs are overprinted with tectonic fractures. Vuggy and (or) fracture porosity have formed local high-quality reservoirs in the Knox Group, but, in general, reservoirs are very discontinuous and heterogeneous. The most extensive zones of vuggy porosity in the play are probably directly beneath the Middle Ordovician Knox unconformity as a result of widespread subaerial exposure and karst processes.

Tectonic fractures of extensional and compressional origin have improved the reservoir quality of karst-related porous zones and, in some cases, may be the sole cause of the reservoir. Most of the fractures probably resulted from differential movement of fault-bounded basement blocks.

Source rocks: The Middle and Upper Ordovician Utica Shale and Scales Shale of the Maquoketa Group are the likely sources of oil and gas on the Findlay and Kankakee Arches and on the north flank of the Jessamine (Lexington) Dome. In contrast, the source of oil and gas in the Cumberland Saddle and Nashville Dome most likely is the Upper Devonian Chattanooga Shale. The Utica Shale in western Ohio is approximately 200 ft thick, whereas the Scales Shale of the Maquoketa Group in eastern Indiana is approximately 100 ft thick. In the Sebree Trough, a region of deeper water sedimentation that extended from southern Indiana through northwestern Ohio during Middle and early Late Ordovician time, the "Utica" shale is between 250 and 300 ft thick. The Chattanooga Shale in the Cumberland Saddle ranges in thickness from 25 to 50 ft.

Total organic carbon values for the Utica and Scales Shales range between 0.5 and 2.0, and its organic matter consists of type II kerogen. Total organic carbon values of the Chattanooga Shale in the Cumberland Saddle range from 7 to 16 and the organic matter contains type I and type II kerogen.

Based on CAI, vitrinite reflectance, and T_{max} data, the Utica, Scales, and Chattanooga Shales are at the beginning of the zone of oil generation. Oil and wet thermal gas are the expected hydrocarbon types.

Timing and migration: Oil and gas probably were generated from the Utica, Scales, and Chattanooga Shales on the Cincinnati Arch in Late Pennsylvanian to Early Triassic time. Short-range migration from the black-shale source beds charged available traps. Given their present-day shallow depth of burial, it is surprising that source beds in the Findlay Arch, Kankakee Arch, and Cumberland Saddle are in the zone of oil generation, as geochemical data indicate. Either the thickness of overburden or the geothermal gradient in these parts of the Cincinnati Arch, prior to post-Mesozoic uplift and erosion, was greater than previously calculated. Very likely, locally derived oil and gas on the Cincinnati Arch was mixed with more distantly derived oil and gas from the flanking Appalachian, Michigan, and Illinois Basins.

Traps: Stratigraphic, combination, and structural traps have trapped oil and gas in this play. Stratigraphic traps consist of truncation and paleotopographic traps situated beneath the widespread Knox unconformity, whereas structural traps consist of small anticlines that very likely have been controlled by basement tectonics. The combination traps are caused by facies and (or) diagenetic changes across anticlinal flanks and noses. Closure on the traps may cover an area as large as 2,000 acres. Drilling depths to the traps range from about 500 to 4,000 ft.

Seals for the traps consist of argillaceous dolomicrite and shale of the Middle Ordovician Wells Creek Formation (Dolomite) and argillaceous micrite of the Middle Ordovician Black River Limestone and High Bridge Group.

Exploration status: Approximately 4,000 holes have been drilled through all or part of the Knox Group in the Cumberland Saddle. Since 1915, approximately 65 oil and gas fields have been discovered that involve the Knox Group. About 17 of these fields produce solely from the Knox Group, whereas the remaining 48 fields have Knox production that is commingled with Middle to Upper Ordovician limestone production.

Through 1991, an estimated 5 MMBO was produced from the Knox Group in the Cumberland Saddle of Kentucky and Tennessee. The four largest fields in the Cumberland Saddle part of the play are Pickett Chapel-Exie South (Adair and Green Cos., KY.), discovery date 1974, depth 1,400–1,700 ft, ultimate recovery ÷1.5 MMBO; Gradyville East (Adair Co., Ky.), discovery date 1969, depth 1,500–1,800 ft, ultimate recovery ~1.0 MMBO; Maple Branch (Adair Co., Ky.), discovery date 1971, depth 1,400–1,500 ft, ultimate recovery ÷0.2 MMBO; and Thomas Ridge (Casey Co., Ky.), discovery date 1961, depth 1,700 ft, ultimate recovery ÷0.1 MMBO.

The number of holes drilled to the Knox Group greatly diminishes north and south of the Cumberland Saddle. Probably no more than 500 drill holes have tested the Knox Group on the crest and flanks of the Jessamine (Lexington) Dome, Cincinnati Arch proper, Findlay Arch, and Kankakee Arch. The Knox Group on the crest and flanks of the Nashville Dome has been tested by no more than 150 drill holes. Except for minor oil production from the Tiffin (Seneca Co., Ohio) and Red Key (Jay Co., Ind.) fields, no Knox oil fields are known outside the Cumberland Saddle.

Resource potential: This play has potential for a small number of undiscovered oil and gas fields greater than 1 MMBO and 6 BCF of gas. The main reasons for expecting undiscovered fields in the play (1) are the subtle nature of the traps, (2) the enormous area with sparse drilling to the Knox Group, (3) the presence of hydrocarbons in the Knox Group throughout much of the Cincinnati Arch Province (066), and (4) mostly untested lower parts of the Knox Group. The greatest limiting factor to the play may be that reservoirs are widely scattered and of low quality.

6602. MIDDLE AND UPPER ORDOVICIAN CARBONATE PLAY

The Middle and Upper Ordovician Carbonate Play is defined by oil and associated gas trapped in vuggy platform dolomite and bioclastic limestone by facies-change stratigraphic traps, dolomitized fracture zones, and small anticlines controlled by basement faults. Stratigraphically, the play involves the Middle and (or) Upper Ordovician Trenton Limestone, Black River Limestone, High Bridge Group, Lexington Limestone, Stones River Group, and Nashville Group. The play is confirmed and extends across the entire Cincinnati Arch except along crests of the Jessamine (Lexington) and Nashville Domes where the Middle and Upper Ordovician sequence has been eroded. Most limestone and dolomite reservoirs in the play are classified as conventional.

Reservoirs: Pervasively dolomitized bioclastic limestone in the upper 100–200 ft of the Trenton Limestone is the primary reservoir of the Lima-Indiana field. The reservoir extends across at least 5,000 sq mi of northeastern Ohio and north-central Indiana. The origin of the regional dolomitization is unknown. Two plausible models are (1) subaerial exposure and mixing with meteoric water and (2) mixing with heated subsurface brines that migrated onto the arch. Vuggy, biomoldic, and intercrystalline porosity are the dominant porosity types. Dissolution of fossil fragments probably occurred both before and after (or during) dolomitization. Large vugs lined with coarsely crystalline white dolomite are associated with fault zones along which warm dolomitizing fluids probably percolated. Initial oil production was very high from these zones of enlarged vugs, but sustained yields were dependent on zones of good intercrystalline porosity.

Bioclastic limestone with biomoldic and intergranular porosity is the dominant reservoir in the Cumberland saddle part of the play. Biomoldic porosity formed mostly by the leaching of fossil fragments during brief periods of subaerial exposure. The most common reservoirs are the Granville zones in the Upper Ordovician part of the Lexington Limestone and unnamed zones in the Upper Ordovician Clays Ferry Formation. The thickness of reservoirs ranges from about 4 to 30 ft.

Narrow fault-controlled zones of dolomitized limestone, such as those in the Lima-Indiana field and the Albian-Scipio field of the Michigan Basin, may be important in other parts of the Cincinnati Arch Province; however, to date, no significant production has been reported from these types of reservoir elsewhere in the province.

Tectonic fractures of extensional and compressional origin have improved the quality of the limestone and dolomite reservoirs and, in some cases, may be the sole cause of the reservoir. Most of the fractures probably resulted from differential movement of fault-bounded basement blocks.

Source rocks: The Middle and Upper Ordovician Utica Shale and the Scales Shale of the Maquoketa Group are the likely sources of oil and gas on the Findlay and Kankakee Arches and on the north flank of the Jessamine (Lexington) dome. In contrast, the source of oil and gas in the Cumberland Saddle and Nashville Dome most likely is the Upper Devonian Chattanooga Shale. The Utica Shale in western Ohio is approximately 200 ft thick, whereas the Scales Shale of the Maquoketa Group in eastern Indiana is approximately 100 ft thick. In the Sebree Trough, a region of deeper water sedimentation that extended from southern Indiana through northwestern Ohio during

Middle and early Late Ordovician time, the "Utica" shale is between 250 and 300 ft thick. The thickness of the Chattanooga Shale in the Cumberland Saddle ranges from 25 to 50 ft.

Total organic carbon values for the Utica and Scales Shales range between 0.5 and 2.0, and its organic matter consists of type II kerogen. Total organic carbon values of the Chattanooga Shale in the Cumberland Saddle range from 7 to 16, and its organic matter contains type I and type II kerogen.

Based on CAI, vitrinite reflectance, and T_{max} data, the Utica, Scales, and Chattanooga Shales are in the beginning of the zone of oil generation. Oil and wet thermal gas are the expected hydrocarbon types.

Timing and migration: Oil and gas probably were generated from the Utica, Scales, and Chattanooga Shales on the Cincinnati Arch in Late Pennsylvanian to Early Triassic time. Short-range migration from the black-shale source beds charged available traps. Given their present-day shallow depth of burial, it is surprising that source beds in the Findlay Arch, Kankakee Arch, and Cumberland Saddle have reached the zone of oil generation, as geochemical data indicate. Either the thickness of overburden or the geothermal gradient in these parts of the Cincinnati Arch, prior to post-Mesozoic uplift and erosion, was greater than previously calculated. Very likely, locally derived oil and gas on the Cincinnati Arch was mixed with more distantly derived oil and gas from the flanking Appalachian, Michigan, and Illinois Basins.

Traps: Stratigraphic, combination, and structural traps have trapped oil and gas in this play. In the Lima-Indiana field, the important traps are (1) an updip pinchout of porous dolomite, (2) anticlinal and fault traps along the Bowling Green Fault, and (3) facies changes. Traps in the Cumberland Saddle part of the play consist of facies changes from bioclastic limestone to micrite or shale and small anticlines that very likely have been controlled by basement tectonics. Combination traps, caused where facies and (or) diagenetic changes cross anticlinal flanks and noses, also are present in the Cumberland Saddle. Closure on the traps cover an area as large as 5,000 acres. Drilling depths to the traps range from about 500 to 3,000 ft.

Seals for the traps consist of micrite and dolomitic micrite of the Lexington Limestone, shale and argillaceous micrite of the Clays Ferry Formation, and micrite of the High Bridge Group.

Exploration status: Approximately 4,000 holes have been drilled through all or part of the Middle and Upper Ordovician sequence in the Cumberland Saddle. Since the drilling of the Great American well in 1829, approximately 160 oil and gas fields have been discovered in the play. About 112 of these fields produce solely from the Middle and Upper Ordovician limestone sequence, whereas the remaining 48 fields have Middle and Upper Ordovician limestone production that is commingled with Knox Group production.

Through 1991, an estimated 10 MMBO of oil and an unknown amount of associated gas have been produced from Middle and Upper Ordovician limestone reservoirs in the Cumberland Saddle. Among the largest fields are Bakerton (Cumberland Co., Ky.), discovery date 1866, depth 400–1,400 ft; Decide (Clinton Co., Ky.), discovery date 1944, depth 600 ft; Ida (Clinton Co., Ky.), discovery date 1960, depth 600–1,700 ft; Kettle Creek (Cumberland Co., Ky.), discovery date 1922, depth 200–1,100 ft; Lee Chapel consolidated (Clinton Co., Ky.), discovery date 1975, depth 900–2,000 ft; Sulphur Creek (Cumberland Co., Ky.), discovery date 1906, depth 200–1,600 ft; Sulphur Lick (Monroe Co., Ky.), discovery date 1964, depth 500–600 ft; Willis Creek (Clinton Co., Ky.), discovery date 1943, depth 300–400 ft; and Wirmington (Overton Co., Tenn.), discovery date 1981, depth 1,400–1,500 ft. Cumulative production and ultimate recovery estimates are not available for these fields; however, judging from annual and cumulative oil production statistics, by county, these fields probably range in size from 0.5 to 1.5 MMBO. High-yield oil wells from fractured limestone reservoirs, drilled in the 1990's, have created a lot of attention but probably will not add significantly to the reserves of the play.

Approximately 100,000 wells have been drilled in the Lima-Indiana field since its discovery in 1884. The field is essentially depleted but 5–10 holes are drilled each year around its perimeter. The number of holes drilled to the Middle and Upper Ordovician limestones diminishes abruptly to about 500 in part of the province outside the Lima-Indiana field and Cumberland Saddle. Approximately 20 small gas fields have been discovered on the flanks of the Jessamine(Lexington) and Nashville Domes by these drill holes.

Resource potential: This play has potential for a small number of undiscovered oil and gas fields greater than 1 MMBO and 6 BCF of gas. The main reasons for expecting undiscovered fields in the play are (1) the subtle nature of the traps, (2) large areas of sparse drilling to Middle and Upper Ordovician limestone, (3) close proximity to mature source rocks, and (4) the presence of hydrocarbons throughout most of the play area. The greatest limiting factor to the play may be that reservoirs are widely scattered and of low quality.

6603. SILURIAN AND DEVONIAN CARBONATE PLAY

The Silurian and Devonian Carbonate Play is defined by oil and gas trapped in Silurian and Devonian platform carbonates by truncation, facies change, and combination traps. Stratigraphically, the play involves the Upper Silurian Louisville Limestone, Upper Silurian Laurel Dolomite, Middle Devonian Jeffersonville Limestone, and Middle Devonian Boyle Dolomite. Thin sandstone units such as the Upper Devonian Hardin Sandstone and Knob Lick sandstone are included in the play. The driller's term "Corniferous" limestone or interval is commonly applied to one or all of the previously named units. The play is confirmed and extends across the Cumberland Saddle and adjoining flanks of the Jessamine (Lexington) and Nashville Domes. The limestone, dolomite, and minor sandstone reservoirs in the play are classified as conventional.

Reservoirs: Primary reservoirs in the play are vuggy dolomite and limestone formed by karst processes during regional pre-Upper Devonian uplift and erosion. Intercrystalline and intergranular porosity supplement the vuggy porosity. These porosity zones form high-quality reservoirs that are continuous across 15,000–20,000 acres. Locally, tectonic fractures, probably resulting from differential movement of fault-bounded blocks, may have improved the reservoir quality of the vuggy, intercrystalline, and intergranular porosity zones.

Source rocks: The Upper Devonian Chattanooga Shale that rests directly on many of the reservoir units is the source of the oil and gas. The equivalent New Albany Shale in western Kentucky also may have contributed oil and gas to the play. The thickness of the Chattanooga Shale in the Cumberland Saddle ranges from 25 to 50 ft. Total organic carbon values of the Chattanooga Shale in the Cumberland Saddle and adjoining flanks of the Jessamine (Lexington) and Nashville Domes range from about 7 to 16. The organic matter contains type I and type II kerogen. Based on CAI and vitrinite reflectance data, the Chattanooga Shale in the Cumberland Saddle is in the beginning of the zone of oil generation. Here, oil and wet thermal gas are the expected hydrocarbon types. The Chattanooga and New Albany Shales on the flanks of the Jessamine (Lexington) Dome are thermally immature.

Timing and migration: Oil and gas probably were generated from the Chattanooga Shale in the Cumberland Saddle in Late Pennsylvanian to Early Triassic time. Short-range migration of oil and gas from these black shale source beds charged available reservoirs and traps. Very likely, some of the oil and gas in Silurian and Devonian reservoirs migrated from western Kentucky where the New Albany Shale had reached a higher level of thermal maturity.

Traps: Truncation beneath a regional pre-Upper Devonian unconformity has trapped most of the oil and gas in the play. Facies-change traps and combination traps involving facies and (or) diagenetic changes that cross anticlinal flanks and noses are of secondary importance. Closure on truncation traps may cover an area as large as 15,000 acres. Drilling depths to the traps range from about 500 to 1,500 ft. Black shale of the Chattanooga Shale is the seal for most traps.

Exploration status: Approximately 5,000 holes have been drilled through all or part of the Silurian and Devonian sequence in the Cumberland Saddle and adjoining flanks of the Jessamine (Lexington) and Nashville Domes. Since 1865, approximately 235 oil fields with associated gas and 45 nonassociated gas fields have been discovered in the play. Of these fields, about 174 oil fields and 30 gas fields produce exclusively from the "Corniferous" interval. The remainder of the fields have "Corniferous" production that is commingled with Mississippian (major) and Ordovician (minor) reservoirs.

Through 1991, an estimated 55 million barrels of oil and an unknown amount of gas have been produced from Silurian and Devonian reservoirs in the Cumberland Saddle. Among the largest fields are Bowling Green (Warren Co., Ky.), discovery date 1918, depth <1,000 ft, ultimate recovery ("Corniferous" and Mississippian reservoirs) 12 MMBO; Greensburg (Green and Taylor Cos., Ky.), discovery date 1959, depth <1,000 ft, ultimate recovery 22 MMBO; Le Grands (Hart Co., Ky.), discovery date-1929, depth <1,000 ft, ultimate recovery 4 MMBO; and Logsdon Valley (Hart Co., Ky.), discovery date 1931, depth <1,000 ft, ultimate recovery 2 MMBO.

Resource potential: This play has no potential for undiscovered oil and gas fields greater than 1 MMBO and 6 BCF of gas. The shallow depth of the reservoirs and the high drilling density in the play area suggest that the play is exhausted except for small fields.

6605. MISSISSIPPIAN CARBONATE PLAY

The Mississippian Carbonate Play is defined by oil and gas trapped in Mississippian bioherms and platform limestone by facies-change and local combination traps. Stratigraphically, the play involves the Lower Mississippian Fort Payne Formation and the Upper Mississippian Warsaw, St. Louis, Salem, and Monteagle Limestones. The play is confirmed and is mainly in the Cumberland Saddle and adjoining flanks of the

Jessamine (Lexington) and Nashville Domes. The limestone reservoirs in the play are classified as conventional.

Reservoirs: Primary reservoirs in the play are (1) vuggy, bioclastic, cherty limestone reservoirs of biohermal origin in the Lower Mississippian Fort Payne Formation and (2) oolitic and bioclastic limestone in the Upper Mississippian limestone sequence. Vuggy and intergranular porosity are the dominant porosity types. Although the reservoirs in the play are of high quality, they commonly cover no more than several hundred acres. Tectonic fractures, probably resulting from differential movement between fault-bounded basement blocks, locally may have improved reservoir quality.

Source rocks: The Upper Devonian Chattanooga Shale that is a short distance beneath many of the reservoir units is the source of the oil and gas. The equivalent New Albany Shale in western Kentucky also may have contributed oil and gas to the play. The thickness of the Chattanooga Shale in the Cumberland Saddle ranges from 25 to 50 ft. Total organic carbon values of the Chattanooga Shale in the Cumberland Saddle and adjoining flanks of the Jessamine (Lexington) and Nashville Domes range from about 7 to 16. The organic matter contains type I and type II kerogen. Based on CAI and vitrinite reflectance data, the Chattanooga Shale in the Cumberland Saddle is in the beginning of the zone of oil generation. Here, oil and wet thermal gas are the expected hydrocarbon types. The Chattanooga and New Albany Shales on the flanks of the Jessamine (Lexington) Dome are thermally immature.

Timing and migration: Oil and gas probably were generated from the Chattanooga Shale in the Cumberland Saddle in Late Pennsylvanian to Early Triassic time. Short-range migration of oil and gas from these black shale source beds charged available reservoirs and traps. Very likely, some of the oil and gas in the Mississippian reservoirs migrated from western Kentucky where the New Albany Shale had reached a higher level of thermal maturity.

Traps: Facies-change accounts for most of the oil and gas trapped in the play. Locally, facies-change in combination with anticlinal flanks and noses may have trapped hydrocarbons. Seals for the traps consist of cherty micrite in the Fort Payne Formation and micrite and argillaceous micrite in the Upper Mississippian limestone sequence. Drilling depths to the traps range from 250 to 1,000 ft.

Exploration status: Between 5,000 and 10,000 holes have been drilled through all or part of the Mississippian sequence in the Cumberland saddle and adjoining flanks of the Jessamine(Lexington) and Nashville domes. Since the late 1880's, approximately 140 oil fields with associated gas and 30 nonassociated gas fields have been discovered in the play. About half of these fields also produce from "Corniferous" limestone and (or) Ordovician carbonate reservoirs.

Through 1991, an estimated 7 MMBO and an unknown amount of gas have been produced from Mississippian limestone reservoirs in the Cumberland Saddle and adjoining flanks of the Jessamine (Lexington) and Nashville Domes. The largest of the Fort Payne fields are located in Metcalfe and Wayne Counties, Kentucky. Each of the five largest fields that produce oil from Fort Payne reefs are about 1 MMBO in size.

Resource potential: This play has no potential for undiscovered oil and gas fields greater than 1 MMBO and 6 BCF of gas. The shallow depth of the reservoirs and the high drilling density in the play area suggest that the play is exhausted except for small fields.

UNCONVENTIONAL PLAY

Continuous-Type Play

6604. DEVONIAN BLACK SHALE GAS PLAY

By R.T. Ryder and J.R. Hatch

The Devonian Black Shale Gas Play is defined by gas generated and trapped in fractured black shale of the Upper Devonian Chattanooga and New Albany Shales. The play is hypothetical and extends across the Cumberland Saddle and adjoining flanks of the Jessamine (Lexington) and Nashville Domes. The fractured shale reservoirs are classified as unconventional. This play is characterized as a continuous-type accumulation because (1) the reservoir is low-permeability, fractured black shale, (2) gas is derived locally from the black shale, (3) formation pressure is abnormally low, and (4) there are gas shows or production in most holes drilled.

Reservoirs: The reservoir in the play is fractured black shale in the Upper Devonian Chattanooga and New Albany Shales. The origin of the fractures is related to one or more of the following mechanisms: abnormally high formation pressure caused by the generation of oil and (or) gas, basement tectonics, anticlinal flexures, and post-Paleozoic uplift of the region.

Source rocks: The gas-bearing fractured reservoirs of the Upper Devonian Chattanooga and New Albany Shales are self-sourced. In other words, the gas is derived locally from the black shale. The thickness of the Chattanooga Shale in the Cumberland Saddle and eastern flank of the Jessamine (Lexington) Dome ranges from 25 to 50 ft. The New Albany Shale on the west flank of the Jessamine(Lexington) Dome is slightly thicker. Total organic carbon values of the Chattanooga and New Albany Shales in the play area range from about 7 to 16. The organic matter in the Chattanooga Shale contains type I and type II kerogen, whereas the New Albany Shale contains type III kerogen. Based on CAI and vitrinite reflectance data, the Chattanooga Shale in the Cumberland Saddle is in the beginning of the zone of oil generation. The Chattanooga and New Albany Shales on the flanks of the Jessamine (Lexington) Dome are thermally immature.

Timing and migration: Oil and gas probably were generated from the Chattanooga Shale in the Cumberland Saddle in Late Pennsylvanian to Early Triassic time. The oil migrated into overlying and underlying carbonate reservoirs, whereas much of the gas was adsorbed on fracture faces, clay particles, and kerogen particles and remained near its point of origin. Probably, the amount of thermal gas generated from organic-rich black shale in the play was rather low because of the low level of thermal maturity of the black shale.

Traps: The gas in the fractured black shale reservoirs is trapped by adjoining zones of unfractured to slightly fractured shale. In some localities, the fractures are associated with anticlinal closure. Drilling depths to the Chattanooga and New Albany Shales range from about 250 to 1,500 ft.

Exploration status: Between 5,000 and 10,000 holes have been drilled into or through the Chattanooga and New Albany Shales in the Cumberland Saddle and adjoining flanks of the Jessamine (Lexington) and Nashville Domes. However, most of these drill holes are not considered to be valid tests of the Chattanooga and New Albany Shales because they were intended for deeper objectives. Since 1890, about 12 small gas fields have been discovered in the Chattanooga and New Albany Shales in the play area. Most of the fields produce gas from both black shale and overlying Mississippian carbonate reservoirs. Although cumulative production has not been recorded for these fields, it is unlikely that any of them are greater than 6 BCF in size..

Resource potential: This play has potential for a small amount of undiscovered gas. Undiscovered gas in the play is assessed using a continuous-type unconventional resource model. This model incorporates (1) probability distributions of estimated ultimate recovery (EUR) per well, (2) optimum area that a well can drain (spacing), (3) number of untested drill sites having the appropriate spacing area, (4) success ratio of previously drilled holes, and (5) risk. EUR's for producing wells in the Chattanooga and New Albany Shales range from 10 (F95) to 300 (F5) MMCFG and have a median (F50) of about 80 MMCFG. The well spacing used in the assessment of the play is 160 acres. A large risk factor is applied to the assessment because of the low level of thermal maturity attained by the Chattanooga and New Albany Shales in the play area.

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